Measurement of flow velocity field in corona discharge radical shower non–thermal plasma reactor

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In this paper results of the Particle Image Velocimetry (PIV) measurements of the flow velocity fields in a corona discharge radical shower (CDRS) non–thermal plasma reactor are presented. The discharge electrode of the CDRS reactor was a thin tube with several nozzles, through which a gas mixture was added to the reactor. The velocity fields were measured in two flow planes perpendicular to the electrode tube: the first plane was set between two nozzles in the middle of the discharge electrode, and the second passed through one of them. In both planes electrohydrodynamically generated vortexes were found. However, in the plane set between the two nozzles, the vortexes were smaller. This investigation shows that in the reactor with the CDRS discharge electrode is used, the vortexes revolve in the opposite direction to those generated in the non–thermal plasma reactors with smooth wire discharge electrodes. The flow patterns in the reactor with CDRS electrode are more stable than those with the smooth wire electrode. This can have an influence on the performance of the CDRS reactors.

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1 Introduction

Non–thermal plasma techniques [1], [2], [3] have become an important tool for controlling the emission of various gaseous pollutants, such as acid gases (SO_x, NO_x, HCl, etc.), greenhouse gases (CO_x, N_xO_y, para–fluorocarbons, etc.), ozone depletion gases (freons, halons, etc.), volatile organic compounds (VOCs, e.g. toluene, xylene, etc.) and toxic gases (Hg, dioxins, etc.). The main advantages of the non–thermal plasma techniques are small space volume, low cost, high pollutant removal and energy efficiencies.

CDRS reactors have been recently proved to be one of the most efficient non–thermal plasma reactor systems used for NO_x removal [4], [5], [6]. In a CDRS reactor, a tubular electrode with one or several nozzles is used for additional gas (NH_3, CH_4, etc.) injection across the corona discharge zone into the main flue gas flow. Due to the additional gas injection the corona discharge produces active species such as NH, NH_2, CH, CH_2, etc., which enhance the removal of NO_x. The performance of the CDRS reactors can be also improved by the transport of the long–life species, caused by the electrohydrodynamic (EHD) secondary flow, as it was suggested in [7].

This investigation concerns the measurements of flow velocity field in a CDRS non–thermal plasma reactor using the PIV method [8]. Collecting such data is important for designing the non–thermal reactors of high performance efficiency.

2 Experimental apparatus

A schematic of the experimental apparatus used for the measurement of the flow velocity fields in the CDRS reactor is shown in Fig. 1. The reactor was an acrylic box of a rectangular geometry (100 mm × 200 mm × 1000 mm) as used by Mizeraczyk et al. [7]. A stainless–steel tube (4 mm in diameter) with 18 stainless–steel nozzle electrodes (1.5 mm outer diameter, 1 mm inner diameter, 5 mm length), soldered into the tube, was used as the CDRS electrode. It was placed in the middle of the reactor, in the halfway between two grounded parallel plate electrodes (200 mm × 600 mm). Positive polarity DC high voltage was applied through a 10 MΩ resistor to the CDRS electrode. The operating voltage was varied from 0 to 31 kV to develop a stable streamer corona discharge from each electrode nozzle to the plate electrodes. The discharge was operated at room temperature under atmospheric pressure.

Two flows, the main and the additional, were established in the reactor. The main gas (ambient air) flowed along the reactor, driven by an induced fan. The mean velocity of the main gas flow was varied from $U_s = 0$ to $U_s = 0.8\ \mathrm{m\,s^{-1}}$, which corresponds to the flow change from laminar to transitional (Reynolds number varied from Re = 600 to 2660 for $U_s = 0.18\ \mathrm{m\,s^{-1}}$ and $U_s = 0.8\ \mathrm{m\,s^{-1}}$, respectively). The standard deviation of the main gas mean velocity was ± 4 %, as measured with the PIV. The additional gas ($N_2 : O_2 : CO_2$=80 % :5 % :15 %) was injected through the nozzles into the main gas flow with a flow rate varied from 0.25 to 1.5 $\mathrm{l\,min^{-1}}$ (nozzle outlet gas velocity ranged from 0.3 to 1.8 $\mathrm{m\,s^{-1}}$, corresponding to Re = 30 – 180, respectively). The presence of CO_2 (15 %) stabilized streamer corona discharge mode, preventing glow and spark discharge modes [9].

The flow velocity fields in the CDRS reactor were measured using the PIV method. The PIV equipment consisted of a twin second harmonic Nd–YAG laser system (λ = 532 nm, pulse energy 50 mJ), imaging optics (cylindrical telescope), CCD camera, image processor (Dantec PIV 1100) and PC computer (Fig. 1). A laser sheet of thickness of 1 mm, formed from the Nd–YAG laser beam by the cylindrical telescope, was introduced into the CDRS reactor as a plane perpendicular to the CDRS electrode. The measurements were performed in two different planes, set perpendicularly to the electrode tube; the first plane passed through the central nozzle, and the second passed the halfway between the central and neighbouring electrodes. Seed particulate (cigarette smoke), being expected to follow the flow, was added to the main gas for scattering the laser–sheet light. The particle images were recorded by the Kodak Mega Plus ES 1.0 CCD camera, which could capture two images with a minimum time separation of 2 μs. The CCD camera active element size was 1008 × 1018 pixels. The captured images were transmitted by the Dantec PIV 1100 image